Exploration of surface milling machining process of C/SiC composites based on quality improvement

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Abstract. C/SiC composites have the advantages of high strength, oxidation resistance and high temperature resistance, which are widely used in aerospace high temperature structures. However, the machining apparent quality has also become an important factor limiting its application. Therefore, this paper investigates the effects of cutting force, tool parameters and tool wear on the apparent quality of ultrasonic vibration milling of C/SiC composites. And the effect of tool selection and tool path on the milling surface roughness of C/SiC compliant materials is proved by experiments. In order to provide certain reference for the improvement of the surface milling quality of C/SiC composite materials.

Keywords: C/SiC composites; milling process; surface roughness.

1. Introduction

Carbon fiber reinforced silicon carbide ceramic matrix (C/ SiC) composites using continuous carbon fiber toughened silicon carbide matrix, with conventional metal materials are difficult to compare the high strength, low density, wear resistance, oxidation resistance, corrosion resistance and other excellent features, has been widely used in the national defense and military, aerospace, high-end automotive manufacturing and other cutting-edge science and technology fields, the rapid development of these fields on the processing of the C/SiC composite components The rapid development of these fields has brought great challenges to the processing of C/SiC composite components[1-2]. This chapter summarizes the research progress of ultra-precision machining of C/SiC composites, and further analyzes the influence of tool selection and tool path on the avoidance of milling of C/SiC composites through experiments.

2. SiC material ultra-precision machining research progress

2.1 Cutting force

Cutting force is the most important factor describing the cutting behavior, and it has a decisive role in the tool behavior during the cutting process[3]. J. Dai et al. conducted a diamond grain single-grain grinding test on silicon carbide (SiC) to study the effect of cutting edge radius and wear on the material removal mechanism during the grinding process. It was found that in the precision grinding of brittle materials with cutting edge radius greater than the maximum depth of cut, there is a critical value of the cutting edge radius, and when it is lower than the critical value, increasing the cutting edge radius improves the machined surface quality, and accordingly, the tangential grinding force (Ft) and normal grinding force (Fn) both increase with the increase of the cutting edge radius, and the tangential force reaches a peak at the cutting edge semi-critical value, and then decreases with the cutting edge radius Then it decreases with the increase of cutting edge radius, and the cutting force has a direct influence on the machining surface quality.

2.2 Tool parameters

Among the important factors affecting tool machining, different tool types and tool angles have a very significant effect on the results of C/SiC ultra-precision machining[4]. Jiang Shengqiang et al.

conducted a discrete element simulation of single-point diamond ultra-precision cutting of C/SiC material to study the effect of machining conditions such as tool rake angle size, depth of cut, and cutting speed on the residual stresses of the workpiece. The study shows that the residual stresses within the C/SiC workpiece are positively correlated with both the cutting speed and the depth of cut, and increase with the increase of the cutting speed as well as the depth of cut, and the influence of the tool angle is relatively complex, when the tool front angle is at a small negative front angle (-20°～0°), the residual stresses after cutting are small, while when the front angle is too large or too small, it will produce a large amount of residual stresses.

During the cutting process, the high-temperature and high-pressure environment in the cutting area is very likely to cause oxidation of the C/SiC material and adhesion to the tool surface, which seriously affects the machined surface quality.Z.P. Li et al. used polycrystalline diamond (PCD) milling cutters to carry out ultra-precision micromilling on high-purity C/SiC to study its machining characteristics. The results show that plastic mode machining can be achieved when the chips removed are thin enough to obtain a high quality surface (Ra = 1.7 nm), however, despite the successful machining of micron-sized small holes and groove structures with nanoscale surface roughness, the machined surface roughness deteriorates progressively and the depth of the small holes becomes shallower as the number of machined holes increases (see Figs. 1 and 2), which is mainly attributed to the adhesion of foreign material on the surface of the tool[5]. This is mainly attributed to the accumulation of dissimilar materials adhering to the tool surface, and energy dispersive X-ray spectrometry (EDS) analysis shows that the adhering material is amorphous SiO2.In order to restore the cutting performance of the PCD tool, the surface of the tool was repaired by adopting a new electrochemical-assisted restoration technique, which effectively removes the surface contamination while not damaging the tool.

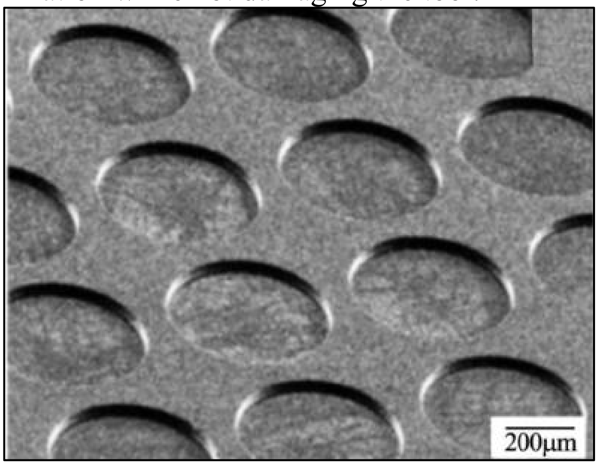
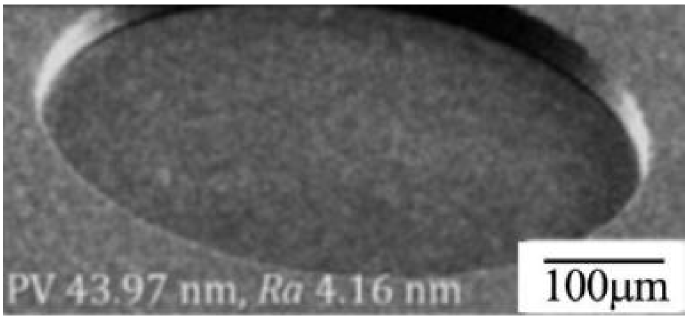


Fig. 1 Surface morphology of all grooves



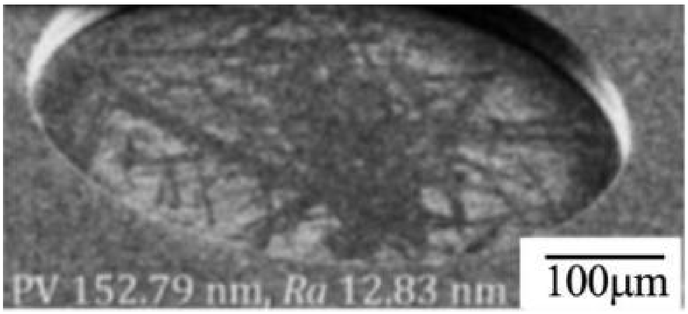
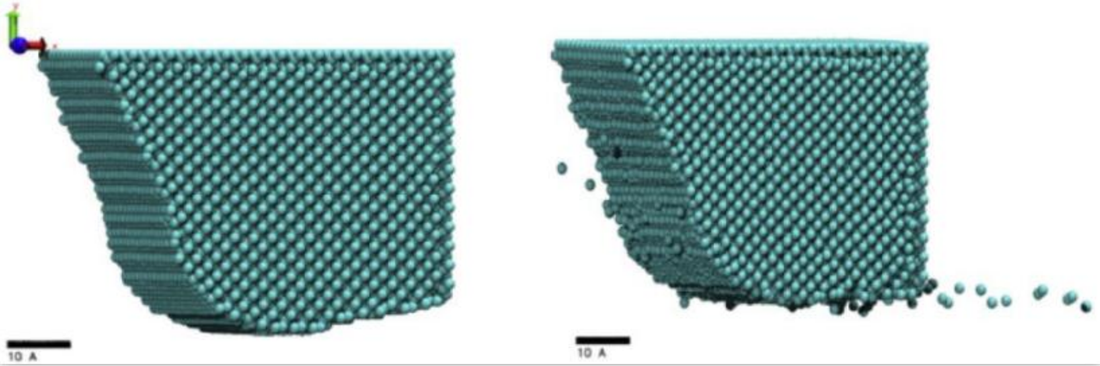


Fig. 2 Surface profile of groove 1 and groove 16

2.3 Tool wear

The hardness of C/SiC material is very large (9.5HM), which is not much different from that of diamond (10HM), and the diamond tool will inevitably wear during the ultra-precision machining process, which will shorten the life and affect the machining surface quality[6]. S. Goel et al. established a molecular dynamics single-point diamond turning (SPDT) nano-simulation of 3C-SiC using the analytical bond level potential (ABOP), investigated the wear mechanism of the diamond tool in the process by using the radial distribution function and so on and quantitatively analyzed it. It is shown that there is a strong abrasive effect between SiC and the diamond tool during the cutting process (see Fig. 3), and the high temperature in the cutting region leads to a decrease in the hardness of the diamond tool. J. Dai et al. conducted diamond grain single-grain grinding tests on silicon carbide (SiC), and found that flanking wear is the main wear mode in precision SiC grinding, and the single-crystalline diamond grains have a higher wear rate, whereas the radial wear rate starts to increase significantly when excessive flanking wear occurs, and the tool wear is related to the Grinding force and grinding surface are also related.



(a) Diamond tool profile before cutting (b) Tool profile at 10.9nm cutting distance.

Fig. 3 Tool wear during turning of SiC with single crystal diamond tools.

3. Experimental materials and methods

3.1 Experimental materials and equipment

The test material is C/C-SiC composite material, prepared by chemical vapor permeation densification, impregnation, curing, cracking and other processes[7]. Ultrasonic vibration three-axis milling CNC machine CKN-200901 (ultrasonic vibration frequency of more than 16,000 vibrations per second, wave ultrasonic processing current of about 110mA) for specimen processing, the apparent quality of the surface roughness measurement by Japan Mitutoyo SJ-210 portable surface roughness measurement instrument for surface roughness characterization.

3.2 Experimental conditions

The C/SiC composites machining experiments were carried out on the KV1400D machining center, and the tools selected were inlaid diamond milling cutter (A), tungsten alloy milling cutter (B), super-hard milling cutter (C), and diamond grinding rods (D), as shown in Figs. 4 and 5. The specimens selected in the experiments were needle-punched C/C-SiC composites prepared by chemical vapor deposition combined with precursor impregnation cracking, the material was carbon cloth/mesh fiber stacked structure, and the needle-punched precursor was composed of two kinds of fibers in the XY direction: disordered distribution of horizontally oriented meshed fibers and regular distribution of carbon cloth carbon fibers[8]. The diameter of the carbon cloth fibers is 7 μm, the volume fraction of fibers is 35%, the volume fraction of carbon matrix is 21%, the volume fraction of silicon carbide matrix is 37%, and the porosity is 7%.

Fig. 4 Various types of tools for testing


Fig. 5 Composite components

3.3 Experimental method

The experiment was carried out under dry cutting conditions, using one-way smooth milling, and in order to study the influence of the existing cutting tools and cutting allowance on the machined surface quality, the one-factor experimental method was used[9]. The machined specimen in the experiment is 150mm×50mm×30mm, and the selected machining parameters are spindle speed

1500r/min, machining feed 100mm/min, and radial cutting width 2mm. the machined specimen is cut and machined to a size suitable for electron microscopy 10mm×50mm×30mm, and the surface of the workpiece is measured by Mitutuyo SJ-210 handheld roughness meter to measure the surface roughness of the workpiece. Since the SiC material itself is anisotropic and has internal pores, three parts of each of the two fiber directions of the specimen were selected for measurement, so as to obtain the most accurate roughness value of the specimen.

4. Tool selection and effect

C/SiC composites belong to anisotropic materials and are highly hard and brittle materials, machining this type of material, the roughness of the product, dimensional accuracy, fiber integrity is the main consideration[10]. For the characteristics of the C/SiC composite materials selected for this experiment, four kinds of tools, namely, inlaid diamond milling cutter, tungsten alloy milling cutter, diamond grinding rod and super-hard milling cutter, are selected for the cutting experiment. The cutting process simulates the product finishing conditions, selecting the machining allowance of 0.4mm, the tool speed of 1500r/min, feed 100mm/min, and use the roughness meter to measure the test object.

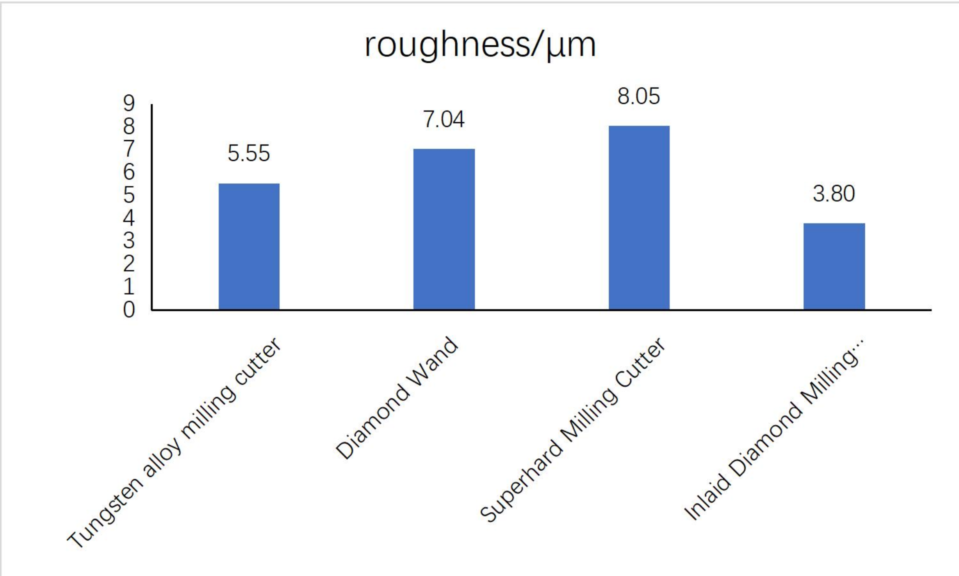


Fig. 6 Effect of tool on roughness

Figure 6 shows the roughness data comparison of the specimen after machining with four cutting tools, due to the poor homogeneity of the C/SiC composite material itself, a single point can not characterize the real roughness value, so the test obtained

The roughness values are the average of the sampled values after multiple points. Through the data comparison, it can be seen that the surface roughness after diamond milling cutter processing is the best, the roughness value is 3.8μm; tungsten alloy milling cutter, diamond grinding rod, super-hard milling cutter compared with the roughness values are higher, reaching 5.55 μm, 7.04 μm and 8.05 μm, respectively. the reason for this situation is the poor wear resistance of the tool, which can not guarantee the sharpness of the tool, so that the surface roughness increases. Electron microscope photographs of the surface after machining with the four kinds of tools magnified 30 times can be seen that a large number of voids appeared in the combined parts of the fibers and the substrate on the machined surface of the tungsten alloy milling cutter, diamond grinding rod, and superhard milling cutter, as well as the phenomenon of fiber pulling out. The surface quality of the fibers on the machined surface of the diamond milling cutter is better, and there are fewer defects of the fibers and matrix pores, so the inlaid diamond milling cutter is used in all the subsequent tests for the study[11].

5. Toolpath impact analysis

Different from metal cutting, in the processing of C/SiC composite materials, the toolpath trajectory not only affects the processing efficiency, but also affects the apparent and microscopic quality of the product, so it is very important to choose a reasonable processing trajectory for C/SiC composite materials to protect the integrity of the fibers in the finishing process. The composite material selected for this test is needle-punched C/C-SiC material, and in order to avoid the damage of unreasonable trajectory on the material in the milling process, four types of toolpaths are selected.

Four types of toolpaths were selected, unidirectional toolpath, longitudinal reciprocating, transverse reciprocating, spiral toolpath, to study the effect of toolpath trajectory on the apparent quality of the material, the machining parameters are n=1500r/min, F=100mm/min, and the depth of cut of the tool is 0.4mm.Fig.7 shows the results of the surface roughness of the milling of C/SiC composite material specimens after adopting the four different toolpaths trajectories respectively[12]. It can be seen that the roughness of the machined surface of the unidirectional toolpath trajectory is the best, with a roughness value of 3.46 μm; the roughness values of the longitudinal reciprocating, transversal reciprocating, and helical toolpaths reach 4.21 μm, 4.03 μm, and 4.09 μm, respectively, and the gap between the three is relatively small. According to the characteristics of the material, the material has longitudinal and transverse fibers, and the removal mechanism of the material is removed by brittle fracture, so the above results indicate that the tool cuts along a single fiber direction (unidirectional tool path) the surface roughness of carbon ceramic material is better. The other cutting methods of machining process, the tool has at least two directions to the material removal, which will make the surface roughness of the material larger.

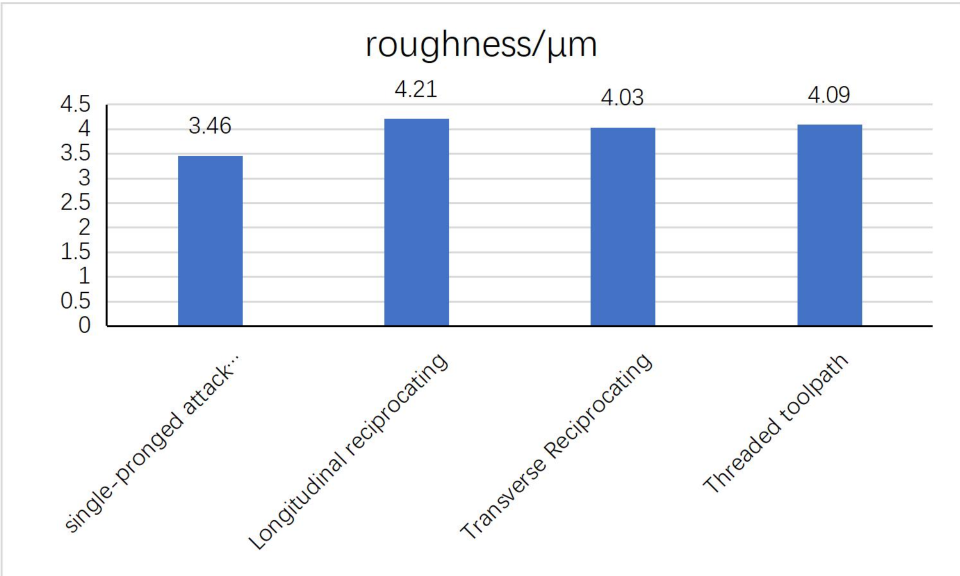


Fig. 7 Effect of tool path on roughness

6. Conclusion

In this paper, the effect of cutting force, tool parameters and tool wear on the apparent quality of ultrasonic vibration milling of C/SiC composites is analyzed. And through the test to prove the influence of tool selection and tool path on the milling surface roughness of C/SiC compliant materials, the results show that the diamond milling cutter processed surface roughness is the best, and the tool cuts along a single fiber direction (unidirectional tool path) the surface roughness of carbon ceramic material is better.

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